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Study on mechanism of overburden rock failure during coal mining with shallow depth and thin bedrock

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Abstract

The paper studies the mechanism of overburden rock failure of Hongshuliang mine of Junger coalfield in Inner Mongolia. With overlying bedrock of shallow depth and thin thickness, after mining the first-extracting coal seam, the instability of overlying rock may result in collapse disaster of sand and water. Then, using plastic softening model and UDEC numerical simulation, deformation and failure laws and mechanism of overburden bedrock are studied during two phases of rock driving and coal mining. Finally, the risk of surface water bodies bursting is evaluated and a reasonable exploitation of programs and prevention measures are put forward, which will provide a valuable reference for exploitation of coal resources in semi-arid areas in China.

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Keywords: mechanism of overburden rock failure; collapse of sand and water; shallow depth and thin bedrock; extracting and coal mining

1. Overview

Belonging to semi-arid region, the Coal Mine located in southern of Inner Mongolia Coalfield, with area of about 30km^2, rainfall average of 32.66mm, the average evaporation of 187.47mm. Most of the region is covered by thick layer of loess, and terrain tilts from higher northwest to lower southeast. Gullies are well developed and GuanZi gully is the major one along the north-south direction, tributaries of Sunny gully, Kong Dulong gully, Shao gully, Nuanquan gully and Qingyangshu gully. All these gullies are generally dry or have only small streams during dry season, however, flood can be formed

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during rainy season. For the direction of mining face intersects with the extension direction of the gully, there is the risk of collapse of sand and water inrush with mining process passing through under the gully bottom repeatedly[1].

This paper will study the mining process of the first mining area. The main gully is Nuanquan gully where a reservoir of small dam situated upstream and downstream a small reservoir is near the mouth of gully. Rain flood carries large amounts of mud and sand in rainy season over the years. Because the landform is cut by gully deeply, bedrocks are exposed widely on both sides of gully, and the thinnest thickness is only 30m form gully bottom to roof of the first mining coal seam. There is the risk of roof fall and collapse of water and sand inrush during excavation and mining phases, so it is hoped that a reasonable exploitation of programs and control measures is put forward, by researching failure laws and mechanism of overburden bedrock during two phase and evaluating the risk of surface water bodies bursting[2].

Since the occurrence of a large quantity of high-quality coal resources in semi-arid areas of China, and Inner Mongolia is one of the richest regions with coal resources, the study will provide an important reference for coal mining safely in these areas.

2. Characteristics of coal seam and overburden strata lithofacies with shallow overburden and thin bedrock

2.1. Characteristics of main mining coal seam and aquifers

Main mining coal seam is in the upper layer in Shanxi Formation, depth 0 ~ 245m, thickness of topsoil and weathered layer 0 ~ 50m. The roof and floor lithologic are mainly mudstone, sandy mudstone and siltstone, and average thickness of coal seam is 6.2m, average mining height being 5.75m range about 4.41 ~ 6.1m, close to full seam mining.

In coalmine's first mining area, aquifers overlying coal seam from top to bottom include Quaternary aquifers(Q), lower Permian Xiashihezi Formation (P_{1x}) and lower Permian Shanxi Formation (P_{1S}), flowing direction of groundwater is from east to west in the overall movement. The coal seam is in the upper layer in the Shanxi Formation, and no hydraulic connection with deep Karst-Fissure aquifer. As no well impermeable layer between Shanxi and Taiyuan Formation aquifers, there is the phenomenon of mutually recharge, the two aquifers become a direct water filling aquifer for coal mining, and its weak Watery Features has already been proved by mixed pumping experiments. The spatial distribution characteristics of first mining coal seam and aquifers are shown in Figure 1.

2.2. Lithofacies characteristics of overburden strata

As different lithologic structure constitutes roofs with different types of mechanical structures, and then roof's affected degrees is also different in mining course. Lithologic structure refers to combinations of lithologic and strength of stratas overlying direct roof under particular condition of overburden layers in mining field, usually there are two combinations of soft strata underlying hard (soft and hard type) or hard strata underlying on the soft (hard and soft type). The brittle rock is easy to crack, while plasticity and toughness rocks not easy, so waterproofing and crack resistance of rocks composed of brittle and plastic rocks alternately will be well. Similarly, the resistance of overburden strata will directly be impacted by lithologic and mechanical structure of strata[3-4].

The overburden strata of coal seam is impacted by the coal accumulating environment and evolved from river system to peat swamp, lithologic combinations are successively sandy mudstone, sandstone, sandy mudstone and sandstone, showing lithological assemblages of hard and soft rock layers. especially, a layer of sandy mudstone with thickness of 6-18m overlying coal seam generally exists and has good impermeable character to prevent groundwater seeping from upper sandstone aquifer. The lithologic characteristics of strata overlying coal seam is shown in Table 1.

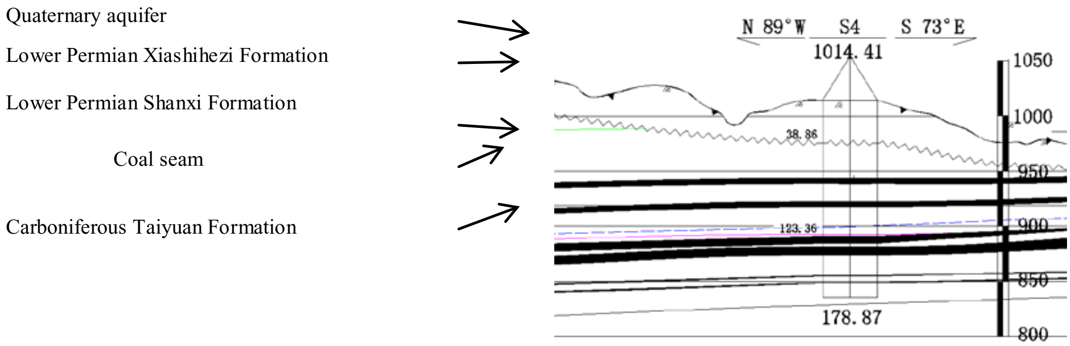

Figure 1 The spatial distribution characteristics of first mining coal seam and aquifers

Table 1 The lithologic characteristics of strata overlying coal seam

No	Name and description of strata and lithology	Total depth（m）	Average thickness of strata（m）
1	Topsoil: the Quaternary loess layer, thick layer, gray sand, loose, not cemented.	31.55	31.55
2	Medium-grained sandstone: gray, thick-bedded, medium-grained sand-like structure, composition of quartz, feldspar-based, with dark cutting, medium sorting,interstitial material for the clay, semi-hard.	55.90	22.75
3	Sandy mudstone: gray, massive, thick layer, containing a small amount of mica and abundant plant fossils, parallel bedding and wavy bedding, irregular-shaped fracture, semi-hard.	75.05	19.15
4	Fine-grained sandstone: gray-white, thick layer, fine sand-like structure, quartz, feldspar-based, with dark charcoal and debris, even bedding, semi-hard.	103.75	28.7
5	Sandy mudstone: gray, massive, thick layer, containing fragments of mica and plant fossils, parallel bedding and wavy bedding, irregular-shaped fracture, semi-hard.	121.4	17.65
6	Coal	128.35	6.95

3. Mechanism of overburden rock failure during coal mining with shallow depth and thin bedrock

3.1. The failure law of surrounding rock during tunneling

Roadway tunneling damages stress balance of rock, causing stress redistributing and damaging the integrity of surrounding rock in a certain range, and plastic deformation forms a fracture zone, when fractured Zone extends to a certain height even to surface water, surface water will inrush in mine roadway and water inflow will increase rapidly, so it is essential to research damaged scope of surrounding rock because of mine roadway extracting.

The roadway closest to Nuanquan gully is studied, the center point coordinates of roadway (4371260.0, 527196.6) and elevation of 937m, ground elevation 1015m, straight-line distance to center point of the gully bottom is 8327m. Roadway has width of 4m and high of 5m, about 78m distance to ground surface. Rock mechanics parameters are shown in Table 2.

Table 2 Comprehensive Results of rock physical and mechanical properties testing

Name	Internal friction angle (Degrees • min)	Cohesion （Mpa）	Compressive strength of the natural state(Mpa)	Porosity (%)	Tensile strength (Mpa)	Modulus （Et）	Poisson's ratio （β）
Coarse-grained sandstone	30°11′~32°37′	4.6~5.7	28.5	14.77	0.67~1.17	5.1×103~1.49×104	0.18~0.88
Medium-grained sandstone	29°21′	8.2	21.2	11.91	1.93	1.42×104	0.21
Fine-grained sandstone			27.40	9.93	0.6~1.9	1.9×103~1.4×104	0.14~0.26
Sandy mudstone	22°54′~39°52′	6.20~13.00	52.8	6.90	0.90~2.07	1.0×103~3.22×104	0.14~0.47

According to references[5-6], the ideal plastic softening model is applied to analyze mechanical status and scope of the plastic deformation and fracture zone of surrounding rock. Whole rock deformation process is divided into the elastic deformation, plastic deformation and flow softening stages.

According to roadway design and rock mechanical experiment results, take

$$H = 78m, \gamma = 2.67g/cm^3, \sigma_c^* = 0.49MPa, \beta = 1;$$
$$\sigma_c = 3.97Mpa, \mu = 0.305, \varphi = 31^\circ, a = 250m$$

Using above parameters we can derive:

$$P_0 = 78 \times 2.67 \times 9.8 \times 10^{-3} = 2.045MPa$$

Into the formula:

$$K_p = \frac{1+\sin\varphi}{1-\sin\varphi} = 3.124$$

Into the formula:

$$B_0 = \frac{(1+\mu)[(K_P - 1)P_0 + \sigma_C]}{(K_P + 1)} = 2.631\,MPa$$

Into the formula:

$$t = \sqrt{\frac{\beta B_0}{\sigma_c - \sigma_c^* + \beta B_0}} = 0.6561$$

the mechanical status of roadway without supporting conditions, P_i=0。

Into the formula:

$$R_c = a\left[\frac{\frac{2}{K_p+1}\left(P_0 + \frac{\sigma_c + \beta B_0}{K_p - 1}\right)}{P_i + \frac{2(\sigma_c + \beta B_0)}{K_p^2 - 1} + \frac{\sigma_c^*}{K_p} + 1}\right]^{\frac{1}{K_p - 1}} = 306.058cm$$

The calculation results show that, if roadway is excavated width 4m and height 5m, which will produce plastic zone of 306.05cm radius, and rock destruction about 56cm width surrounding roadway. The straight-line distance from calculated point to center point of the gully bottom is 8327m, far greater than rock destruction range during roadway tunneling, so surface water and rain floods during rainy season in gully can not enter roadway.

3.2. Failure law of overburden rocks during mining stage

3.2.1. Classification of shallow overburden and thin bedrock

The thickness of Bedrock is about 5 ~ 80m in mining area, and the thinnest depth from Nuanquan gully bottom to roof of first mining face is only 30m. By analyzing geological and hydrogeological conditions, failing zone and height of water flowing fractured zone，the bedrock is defined as type II according to thickness. To understand subsidence of coal roof and subsidence of ground surface in process of coal mining, the falling law of overburden roof is studied using numerical simulation method[7-8].

3.2.2. Numerical simulating shallow overburden and thin bedrock movement

The simulation software is the latest UDEC3.0 version, released in 1996 by ltasca.

(1) Constructing numerical simulation model

Figure 2 shows the model based on geological conditions of mining area. The model adopts plane strain model, left, right and lower bounders are displacement boundary. Simulated bedrock thickness is 35m, model range 300m * 80m, coal seam thickness 4m, simulated mining thickness 4m. Three cases of overburden rock movement patterns were simulated while excavating 30m, 50m and 100m separately. Take 39m, 60m, 80m, 100m, 110m and 120m in vertical direction.

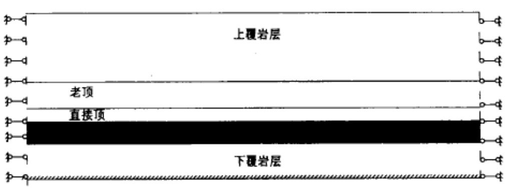

Figure 2 Schematic diagram of numerical simulation model

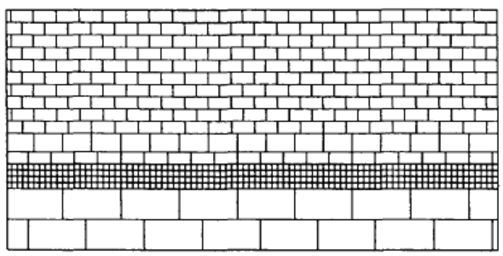

Figure 3 Blocks dividing results in numerical simulation model

Blocks in model are divided based on mechanical strength properties of rock layers and joint distribution, as possible similar to actual distribution of rock mass. The mechanical parameters of surrounding rock are shown in Table 3, and blocks dividing results are shown in Figure 3.

(2) Movement discipline of shallow overburden and thin bedrock

The roof movement patterns under three excavation conditions are shown in Figure 4. It can be seen from the figure： when excavation length is 30m, direct roof and basic roof all falling, direct roof occurred vertical falling along coal walls, and basic roof step-like falling, the ground surface slowly subside and sinking is not clear; excavating 50m, direct roof, basic roof and overburden strata all falling, all overburden rocks will break down corresponding to excavation stage; excavating 100m, whole overburden rocks will break down corresponding to surface subsidence obviously, indicating to fully mining.

Table 3 Mechanical parameters of rock in mining area

Rock name	Density/Kg*m^{-3}	Compressive strength /MPa	Tensile strength /MPa	Cohesion /MPa	Internal friction/(°)	Poisson 's ratio
Loose layer of topsoil	1800	5~13	------	1.5~2.0	8~13	0.4
Fine sandstone	2400	32	1.9	7	38	0.2
siltstone	2400	30	1.05	6	40	0.15
Sandstone	2500	31	1.8	7	36	0.12
Mudstone	2400	48	4.3	10	35	0.12
Conglomerate	2200	33	0.9	3	30	0.20
Sandy mudstone	2400	45	3.53	8	37	0.18
Coal Rock	1370	19	0.95	1.2	38	0.20

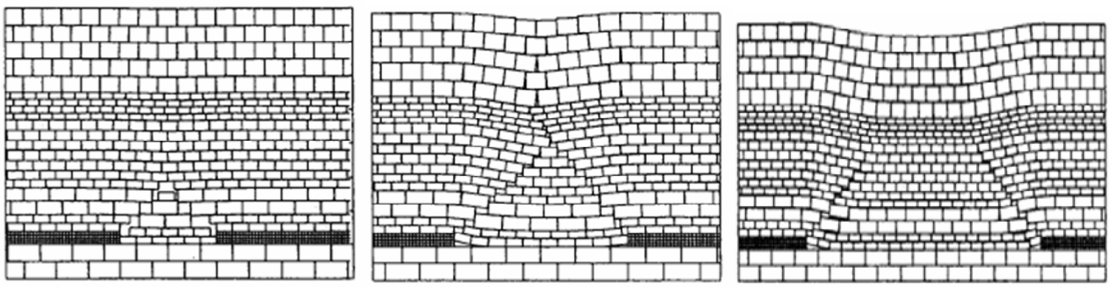

Figure4 Movement patterns of roof rock with bedrock thickness 35m mining 30m, 50m, 100m

In summary, step-like sinking appears for shallow overburden and thin bedrock during mining, vertical falling of coal roof along coal walls causes ground surface sinking gently. As bedrock locating in failing zone and fractured zone without bending subsidence zone, it is obviously "two zones" distribution pattern.

4. Conclusions

Loose stratum widely distributing in mining areas, ground surface is crossed by Nuanquan and Guanzi gullies, groundwater flowing in there through year. The bedrock roof of coal seam becomes thin because of gullies cutting. After analyzing laws of deformation and fracture of overburden rock and surrounding rock during tunnel excavating and face advancing, we can draw following conclusions:

(1) During excavating process, rock will be destroyed about 56cm width around roadway, and plastic deformation zone will extend about radius 306.05cm. It shows that roadway excavating will not impact on ground surface for roof stratum combination in mining area.

(2) Based on laws of roof broken for shallow overburden and thin bedrock, bedrock broken in mining roof will induce cracks and fractures in front of the upper part of main roof. With working face advancing, cracks will continuously expend through overburden layers and finally influence overlying loose layer and aquifer. Under the influence of step-like sinking and falling formation, it is easy to form "Window"

providing channel and place for water and sand inrushing. When coal seam is mined in rainy season, floods caused by rainstorm will bring heavy threat for working face and risk of water of sand inrushing.

(3) Considering topography, geology, rainstorm laws and mining conditions in mining area, prevention methods of water and sand inrushing should be confirmed comprehensively considering technology, economy and other factors. The prevention and treatment measures can be attributed to "ground drainage, roadway discharge, grouting and sand consolidation, gully drainage", complemented by other comprehensive measures such as ground and underground water control technology.

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